RESEARCH GRANT NsG 174-61 to STANFORD UNIVERSITY

A STUDY PROGRAM FOR
THE DEVELOPMENT OF VLF SPACE EXPERIMENTS

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SEMI-ANNUAL STATUS REPORT

for the period 1 March 1965 through 31 August 1965

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A. INTRODUCTION

This report covers briefly the work carried out under the National Aeronautics and Space Administration grant NsG 174-61 over the period 1 March 1965 through August 31, 1965.

The background results and future plans for work under this grant are considered separately under each of the main topics in the following sections.

B. RESULTS

1) Effects of ions. From satellite observations, several phenomena involving ion effects have been discovered or explained at Stanford. The list now includes the following:

(a) Sub-protonospheric whistlers

(b) Transverse whistlers

(c) Low frequency anomalous dispersion of whistlers (especially sub-protonospheric whistlers)

(d) Low frequency cutoff of whistlers (ground-based observations)

(e) Ion gyrofrequency whistlers

(f) Crossover-frequency phenomena

(g) Lower-hybrid resonance emissions

(h) Lower-hybrid resonance whistlers

(i) A new ionospheric duct (hypothesis)

The potential importance of these ion effects is at least as great as that of the ordinary electron whistler. For example, ion gyrofrequency whistlers can yield local proton density, proton temperature, electron density, and the local gyrofrequency -- all obtained from one whistler which is created naturally and which in the future can probably be excited by transmitters on the ground.

The explanation of the low frequency cutoff of whistlers and the associated anomalous dispersion almost certainly involves ion effects. The first efforts along these lines involved consideration of protons and electrons as proposed by Storey [1958] and others. Jack Smith (private communication, circa 1962) proposed that negative hydrogen ions might be necessary. (See also Jack Smith, 1965.) The most likely explanation now appears to involve at least two positive ion constituents (for example, H^+ He^+, or H^+ and O^+).

2) Theory of trapping at the Lower Hybrid Resonance. Data from the Alouette satellite have disclosed bands of ionospheric noise that have interested many workers in the field because of their unusual characteristics. Barrington and Belrose [1963] of Defence Research Telecommunications Establishment, Ottawa, first reported that this noise varied systematically with the position of the spacecraft in the geomagnetic field. They found an example of noise that was sporadic but showed "a systematic tendency for the lowest frequency at which noise is found to decrease as the satellite moved from 41.5° N. to 48° N. Above 48° N. sporadic noise was found throughout the entire frequency range of the vlf receiver with no well-defined lower limit." .."These systematic changes are thought to be due to changes with latitude in the mean drift velocity of the particles which generate ionospheric noise."

Then in the December 15, 1963 Journal of Geophysical Research, Barrington, et al [1963] suggested that the noise was directly under L-value control, cutting off and reappearing at about $L \approx 2.6$ in both hemispheres. They suggested that a "cutoff mechanism might be involved, either due to propagation conditions or with a cutoff in the spectrum of energetic particles that radiate in the vlf band."

In August 1964 Brice and Smith (in work sponsored under this contract) suggested that the change in frequency might arise from "spatial rather than temporal effects." Further, since the noise has features similar to the lower hybrid resonance which defines a cutoff frequency for propagation transverse to the earth's magnetic field, they suggested that this noise occurred at the frequency of the lower hybrid resonance for the ambient plasma. In a companion paper, Brice, et al [1964] deduced that the observed noise band is probably generated at the same height as the satellite and that they are not related to vlf emissions observed on the ground. Furthermore, the noise can be triggered by whistlers and emissions. In a more complete discussion, Brice and Smith [1965] found that the known properties of the band of noise were consistent with the lower hybrid resonance hypothesis.

Belrose and Barrington [1965] presented further data and considered various possible explanations. Later, however, Barrington, et al [1965] reporting on the results of the examination of 400 ionograms, concluded that the "cutoff frequency of the noise band observed in Alouette I vlf records approximates closely the lower hybrid resonance for the plasma."

Here at Stanford University, R. L. Smith had been considering various mechanisms to explain the phenomenon (particularly with reference to its local excitation). An attempt to find an emission mechanism was not successful until he conceived the theory that the LHR noise was "essentially a propagation rather than an emission effect, and results from the trapping of electromagnetic waves propagating nearly transverse to the magnetic field in what amounts to an ionospheric duct or cavity." A preliminary letter-type announcement, "Lower hybrid resonance noise and a new ionospheric duct," by R. L. Smith, I. Kimura, J. Vigneron, and J. Katsufrakis has been prepared suggesting this new theory. This new theory modifies the conclusion that the phenomenon was strictly local to the satellite.

In making plans for new space experiments based on the Byrd vlf transmitter, provision has been made for transmitting the LHR frequencies in an attempt to stimulate the lower hybrid resonance. The current interpretation of the LHR noise indicates that the resonance cavity has a high Q. Presumably the amplitude varies with frequency.

One important result from this theory is that lower hybrid resonance noise may yield information on the helium content of the plasma. The depth of the duct and the bandwidth of the noise depends strongly upon the percentage of helium ions. Therefore, the LHR characteristics may provide new information on the profile of helium ions.

The theory of propagation in multiple component plasmas predicts a whistler similar to the proton whistler but controlled by positive helium ions. The asymptotic frequency is predicted to be the helium gyrofrequency which is somewhat over 100 cycles. The helium whistler, if observed, would yield the density of helium ions. Other techniques have not yielded accurate information about the amount of helium ions in the ionosphere. Additional information on the helium profile in turn improves the definition of the proton and oxygen profile. These exciting possibilities suggest that future vlf antennas should be designed to cover the frequency range of the predicted helium whistler.

It is recommended that the frequency range of future vlf experiments be extended down to at least 50 cycles and preferably to about 10 - 20 cycles to insure adequate definitions of the whistlers and resonance effects discussed above.

It may also be possible to observe effects near the two-ion hybrid resonance [Buchsbaum, 1960] which lies between the helium and hydrogen gyrofrequencies. This resonance is similar to the lower hybrid resonance and a related noise band may possibly be observed at the same time that LHR noise is observed.

3) Ray tracing. After the discovery of the low dispersion whistler called the sub-protonospheric or SP whistler by Carpenter, et al [1964], and the suggestion by Smith [1964] that the peculiar properties of this whistler might be explained by considering the effects of ions and horizontal gradients of electron density in the ionosphere, a ray tracing was carried out including the effect of these ions and horizontal gradients in the ionosphere. I. Kimura and R. L. Smith presented a confirmation of the above theory at the URSI-USNC meeting in Washington, D. C. in April 1965. A full description of the method used will be published in Radio Science in March 1966 entitled "Effects of ions on whistler-mode ray tracing." (Copies of the preprint have already been sent to NASA.)

"This study supported Smith's hypothesis for SP whistlers although it was found that a very critical density profile is necessary to get the observed dispersion characteristics with frequency and the echoing features. The topside sounder record of the ionospheric electron density appears to support such a specific model of the ionosphere." It would seem, therefore, that the SP whistler will prove to be useful in studying vertical profiles and horizontal gradients of density and may provide useful new information on electron density in the F region.

The ray tracing is being used presently by Smith in developing his theory of the lower hybrid resonance trapping, discussed previously.

4) Transverse whistlers. An outgrowth of the examination of the records obtained from Alouette I was the discovery of a new type of relatively short whistler with unusual dispersion properties. A description of the transverse whistler was given at the April 1965 meeting of the URSI USNC in Washington, D.C.

by Kimura, Smith and Carpenter. A description of the anomaly was given by D. L. Carpenter and N. Dunckel [1965]. They compared the frequency-time curve of most ground observed whistlers with that of an Alouette whistler that was not received on the ground and found an anomalous increase in dispersion ($D - tf^{1/2}$) with frequency. An interpretation of the anomaly will be published in the December 1, 1965 Journal of Geophysical Research entitled, "An interpretation of transverse whistlers," by I. Kimura, R. L. Smith, and N. M. Brice. The explanation of the new whistler requires consideration of the possibility of propagation transverse to the magnetic field.

5) Ion gyrofrequency whistlers. One of the more useful discoveries relating to ion effects was the proton whistler, which was discovered at Stanford [Smith, et al, 1964]. Although a number of workers realized that the rising portion of the whistler was due to propagation in the left circularly polarized mode below the proton gyrofrequency, the question of the discontinuous slope and the problem of conversion of the right hand polarized waves in the lower ionosphere into left hand polarized waves was solved independently by two groups at Stanford and the State University of Iowa, and reported in a joint paper [Gurnett, et al, 1965].

Dr. Neil Brice, while working at Stanford University this past summer found that the duration of the proton whistler could be used to yield the temperature of protons. This has since been verified by Brice and Gurnett [1965]. They investigated three effects which might limit the duration of ion cyclotron whistlers: 1) cyclotron damping; 2) ray path deviations near the ion gyrofrequency; and 3) collisional damping. Cyclotron damping was shown to be the most important effect for limiting the duration of proton whistlers. For the observed durations, a temperature of the order of 500 - 700 °K for protons was obtained, which agrees with most of the methods of measurement.

Brice also pointed out that the dispersion of the proton whistler can be used to determine local ion gyrofrequency. Gurnett and Brice [1965] then used a technique of correlating the measured proton whistler dispersions with theoretical dispersions. The results indicate the local proton gyrofrequency (and hence magnetic field) can thus be obtained to an accuracy of 0.1%

A program to continue study of ion gyrofrequency phenomena should include a satellite experiment which can measure polarization. A signal (say from the Byrd Station vlf transmitter) could be swept over a limited range of frequencies covering the expected crossover frequency. The polarization should change from right-hand to left-hand circular. The change in polarization would define the crossover frequency from which the percentage of hydrogen could be deduced. The amplitude as a function of frequency near the ion gyrofrequency could also be found. Sweeping the transmitter frequency around the cutoff frequency would enable one to observe the amplitude vs frequency for a very narrow path. This would provide a refined definition of the cutoff frequency, and hence an improved determination of proton temperature (from cyclotron damping). The transmitter could be used either in the sweeping mode or in an impulse mode for studying the cutoff characteristics associated with cyclotron damping.

6) Sheath study. The study by Crawford and Grard [1965] of the very low frequency measurement of the impedance of the ion sheath which surrounds a probe immersed in a plasma was described in the last report. Their paper on this work has been accepted for publication in the Journal of Applied Physics in its December 1965 issue.

R. J. L. Grard has submitted a thesis for the degree of PhD at Stanford

University entitled "Interpretation of Impedance Probe Measurements in the Ionosphere."* This thesis includes the results of the laboratory experiment designed to investigate the validity of the simplified theory of the sheath. Variations of the sheath impedance with frequency, electron density and probe potential have been examined and presented. A discussion of the effect of the earth's magnetic field and the wake of the rocket on the measurements includes a recommendation for further experimentation. The use of impedance measurements in the ionosphere as a diagnostic technique is also presented.

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*Copies of this thesis will be forwarded to NASA as soon as possible.

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